Saving energy in passenger car transport: between efficiency improvement and increasing car size

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Keywords

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Abstract

In the last years according to the European policy and goals, average fuel intensity of new passenger cars decreased significantly. However, a large part of these efficiency improvements was lost due to the increasing size of cars.

The core objective of this paper is to analyse the change of energy consumption of passenger cars along the energy service (mobility) providing chain (well-to-wheel) of different car types cars (diesel-, gasoline-, natural gas-, battery electric- and fuel cell vehicles) with special focus on the impact of the size of new cars.

The major results of this investigation are: (i) with respect to well-to-tank energy balances there are considerable differences between biofuels, electricity and hydrogen produced from renewable and fossil energy sources; (ii) regarding power-specific fuel intensity there was a decrease of more than 40 % since 1990; that is to say, efficiency in 2010 was much higher than in 1990. (iii) However, about half of these theoretically possible energy savings has been compensated by the switch to larger cars and virtually the same effect can be seen for specific CO_2 emissions.

This leads to the final conclusion that future energy policy has to address the size issue e.g. by means of size-dependent registration taxes.

Introduction

Improving the energy efficiency of passenger cars is considered as an important means for saving energy and reducing CO_2-emissions in transport sector. In the last years according to the European policy and goals, average fuel intensity of new passenger cars decreased significantly. However, a large part of these improvements was lost due to the increasing size of cars.

In Ajanovic, Shipper and Haas (2012) we have analysed general rebounds due to vehicle kilometres driven and size of cars. In this paper we look in-depth by type of fuel.

The core objective of this paper is to analyse energy consumption of passenger cars along the energy service (mobility) providing chain (well-to wheel) of different car types (diesel-, gasoline-, natural gas-, battery electric- and fuel cell vehicles) with special focus on the impact of the size of new cars. Given the data availability the impact of car size can only be analysed for gasoline and diesel cars. Yet, these two types of cars represent about 97 % of all new registered cars over the period analysed.

Method of approach

In this investigation we analyse three major categories of the service mobility providing chain for the average of EU-15 countries over the period 1990–2010 (respectively 2000–2009 for analyses by country):

1. The Well-to-tank (WTT) performance (which includes fuel extraction, conversion respectively production and transport): This analysis is especially important for biofuel-, electricity- and hydrogen-powered cars;
2. The efficiency of the car: We look at fuel intensity per unit of car power (litre/(km kW)) (FIP) as a proxy for efficiency;
3. The size of cars.

Every one of these three categories has a major impact on finally possible energy savings.

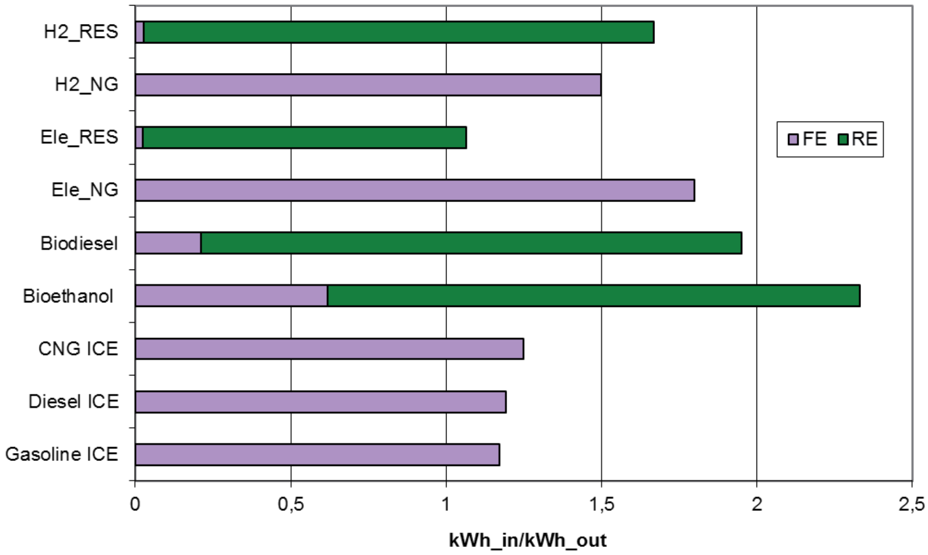

Figure 1. WTT-balances of analysed fuels (Data source: Ajanovic et al, 2012).

Well-to-Tank analysis

The first part of the chain we analyse is the WTT. It provides information for different fuels on how much energy (e.g. in kWh) is needed to produce 1 kWh fuel to be filled in the tank. Figure 1 depicts WTT-performance for fossil fuels (gasoline, diesel and compressed natural gas (CNG)) and for alternative fuels such as biofuels, electricity and hydrogen. Electricity and hydrogen production is considered from renewable energy sources (wind and hydro power) and also from natural gas.

The major results of this investigation are[1]: As shown in Figure 1 there are considerable differences between analysed fuels. For almost all considered alternative fuels total WTT energy balances are higher than by conventional fuels. However there are considerable differences between biofuels as well as electricity and hydrogen produced from renewable and fossil energy sources. Especially high is the energy input in the case of bioethanol produced from wheat. However, using alternative fuels the share of fossil energy in the WTT part can be significantly reduced, especially in the case of electricity and hydrogen produced from renewable energy sources (RES). Yet, if natural gas is used for electricity and hydrogen production total fossil energy consumption in WTT part is even higher than that of conventional fossil fuels.

Tank-to-Wheel analysis

Next the conversion efficiency of fuel into energy service – km driven – is analysed. Usually, fuel intensity (FI) is taken as a measure for fuel efficiency. Fuel intensity is provided in litre per 100 km driven or in kWh per 100 km driven.

Figure 2 depicts development of fuel intensity (in kWh/100 km) for gasoline and diesel vehicles of the average of EU-15 countries for the period 1990–2010. For both, gasoline and diesel cars, decrease in fuel intensity can be noticed over the investigated period, for gasoline even more than for diesel. Moreover, usually diesel cars are favoured because of their lower fuel consumption. Yet, from Figure 2 we can see that actually the difference in energy consumption over the period about 1996 and 2010 was almost neglectable.

Figure 3 shows fuel intensity of new cars by powertrain type in EU-15 in 2010. The analysed car size is 80 kW. Gasoline cars have the highest fuel intensity. Slightly, about 6 %, better is fuel intensity of diesel cars. All analysed alternative automotive systems have much better fuels intensity comparing to gasoline cars. Hybrids consume about 25 % less than their non-hybrid opponents and battery electric vehicles (BEV) and fuel cell vehicles (FCV) even 35 % to 42 % less.

Of specific interest is now, whether there are also differences between the EU-15 countries. As can be seen from Figure 4 and Figure 5 there are considerable differences in fuel intensity across the EU counteris. Figure 4 shows fuel intensity of new gasoline vehicles by country. For the analysed countries fuel intensity of gasoline vehicles is highest in Sweden (62 kWh/100 km) and lowest in France (48 kWh/100 km). This is a difference of about 25 %. Compared to Figure 3 this difference is the same as between gasoline and hybrids!

The situation for diesel cars is similar. Figure 5 shows fuel intensity of new diesel vehicles by country. For this car type fuel intensity is highest in Greece (65 kWh/100 km) and lowest in Portugal (49 kWh/100 km). The difference is even about 28 %.

This fuel intensity of cars has a direct impact on energy consumption and straightforward on the CO_2 emissions. Figure 6 depicts average CO_2 emissions per km driven in analysed EU countries in 2009. There is a very broad range: while countries like France, Italy, Denmark and Portugal purchased on average cars with less than 140 g CO_2/km the other extreme is Sweden with more than 160 average g CO_2/km per new car. It can be noticed that CO_2 emissions are higher in countries with higher fuel intensity of cars used (e.g. Sweden, Greece). CO_2 emissions of the average of all car types are in the range from 133 (Portugal) to 163 (Sweden) g CO_2 per km driven.

1. Note that with respect to WTT performance no remarkable changes took place over the investigated period.

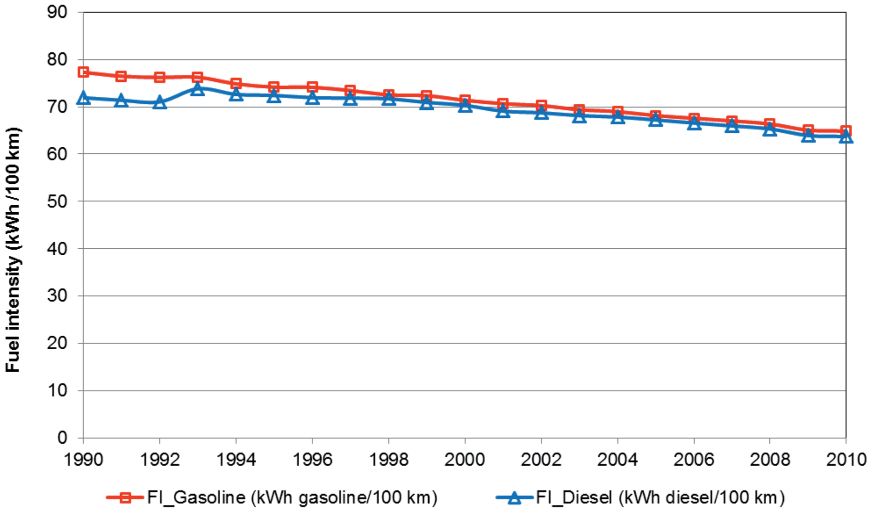

Figure 2. Development of fuel intensity (kWh/100 km) for gasoline and diesel of the average of EU-15 countries 1990–2010 (Data source: Ajanovic et al., 2011).

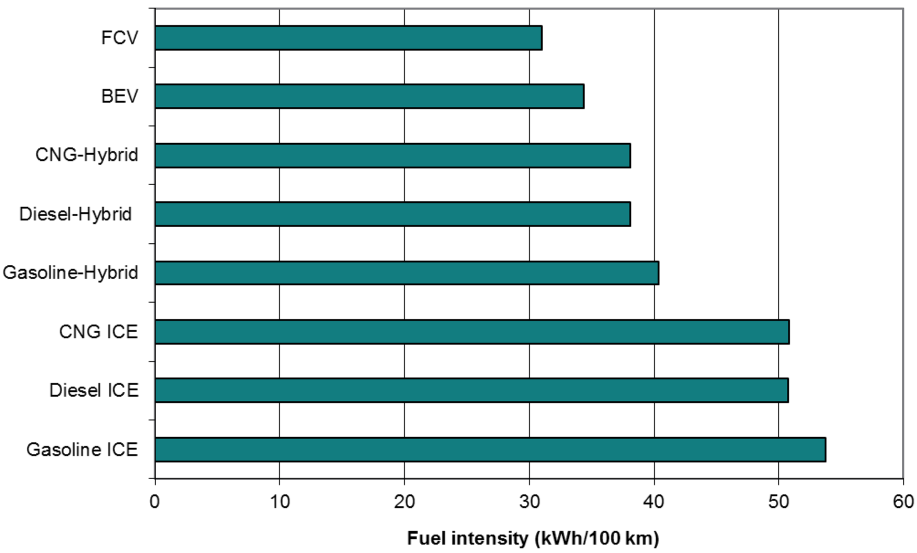

Figure 3. Fuel intensity of new cars in EU-15 (80 kW) in 2010 by powertrain type (Data source: Ajanovic et al, 2011 & 2012).

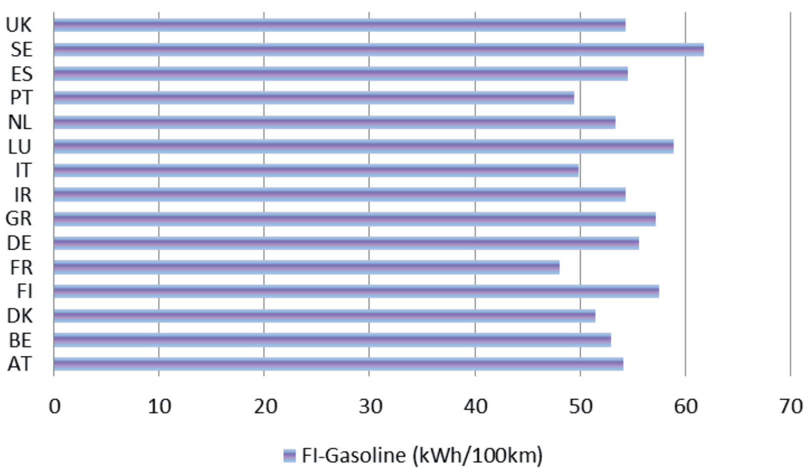

Figure 4. Fuel intensity of new gasoline cars by country (EU-15) in 2009 (Data source: EC, 2009).

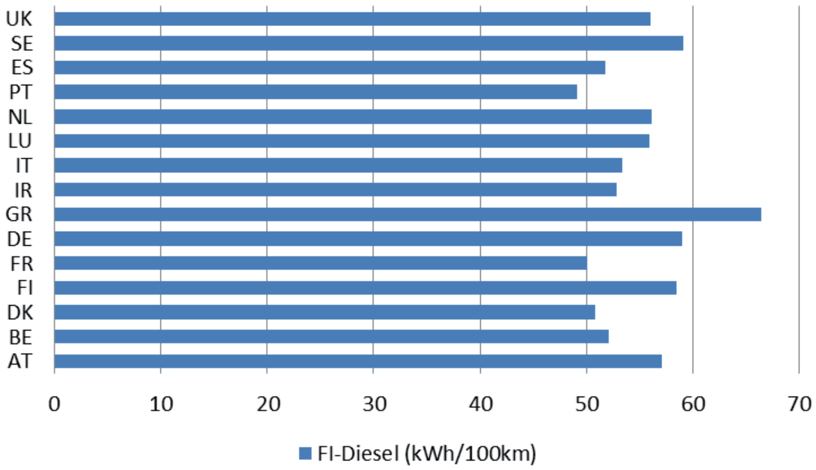

Figure 5. Fuel intensity of new diesel cars by country (EU-15) in 2009 (Data source: EC, 2009).

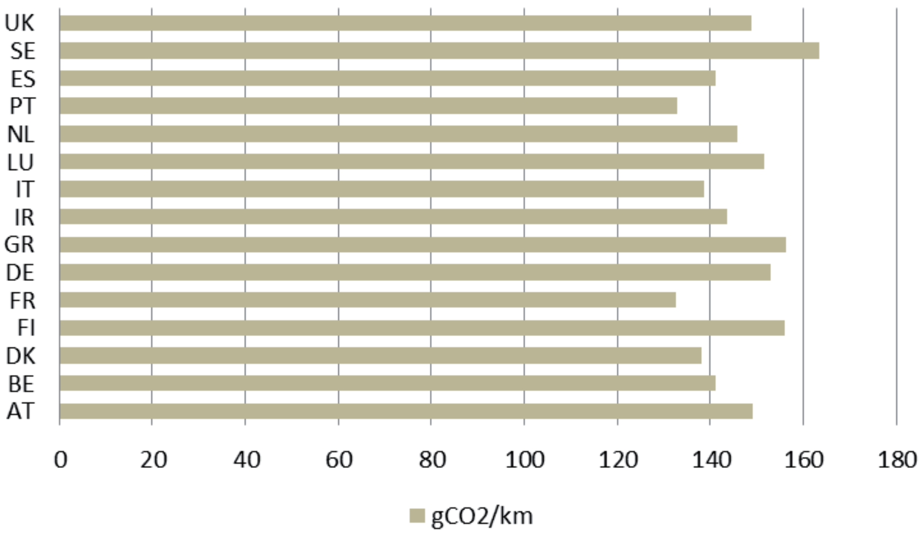

Figure 6. CO_2-emissions (average) by country in 2009 (Data source: EC, 2009).

Size of cars

One of the most important issues regarding the development of average efficiency of cars is the increase in the power or mass of cars. The fact is that due to the increasing size of cars improvements of fuel efficiency of cars are partly lost. Figure 7 documents development of car power in EU-15 for gasoline and diesel cars in the period 1990–2010. Over the period from 2000 to 2006 power of diesel cars was continuously increasing. Power of gasoline cars was almost unchanged between 2004 and 2008. Due to the economic crises slight decrease in car power can be noticed for all fuel types and virtually almost all countries in 2009. However, after 2006 we can see kind of stagnation took place.

The development of car power of gasoline cars by country for the period 2000–2009 is given in Figure 8. Over this period Luxemburg and Greece showed some moderate increase, United Kingdom and France even a slight decrease and all other countries stagnated more or less.

Development of car power of diesel cars by country for a period 1990–2009 is given in Figure 9.

The impact of car size on fuel intensity

The final interesting aspect is how the increases in car size affected fuel efficiency. The fuel intensity (FI) in Figure 2 does not reflect the real efficiency improvement because it is distorted by the switch to larger cars. To correct for this bias a power-specific fuel intensity (FIP) is defined as (see also Schipper, 2008):

$$FIP = \frac{FI}{P} \qquad \text{(litre/(km kW))}$$

P...vehicle power (kW)

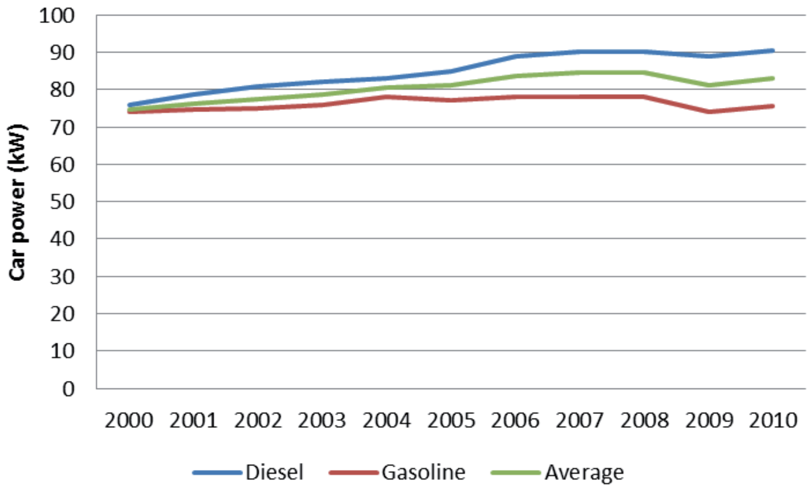

Figure 7. Development of average power of new gasoline and diesel cars in the EU-15 (Data source: EC, 2009 and ACEA).

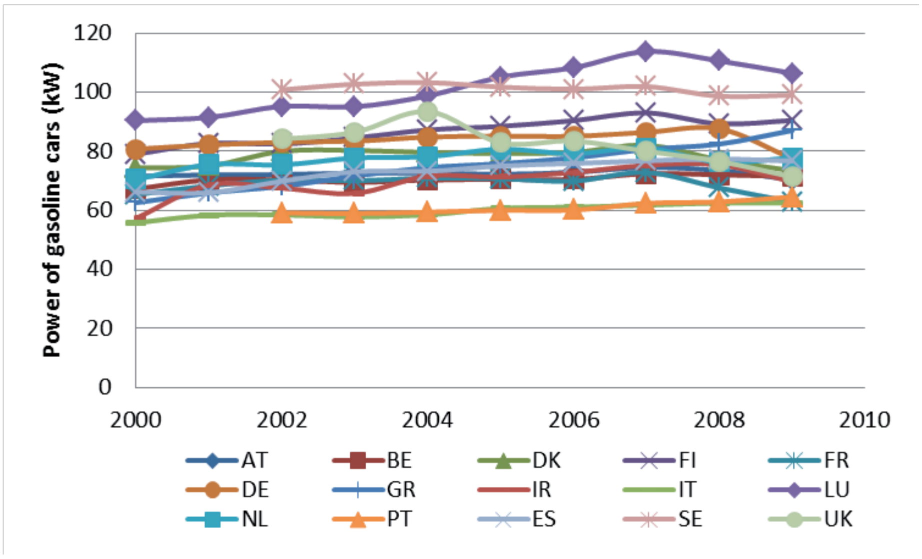

Figure 8. Development of power of gasoline cars by country (2000–2009) (Data source: EC, 2009).

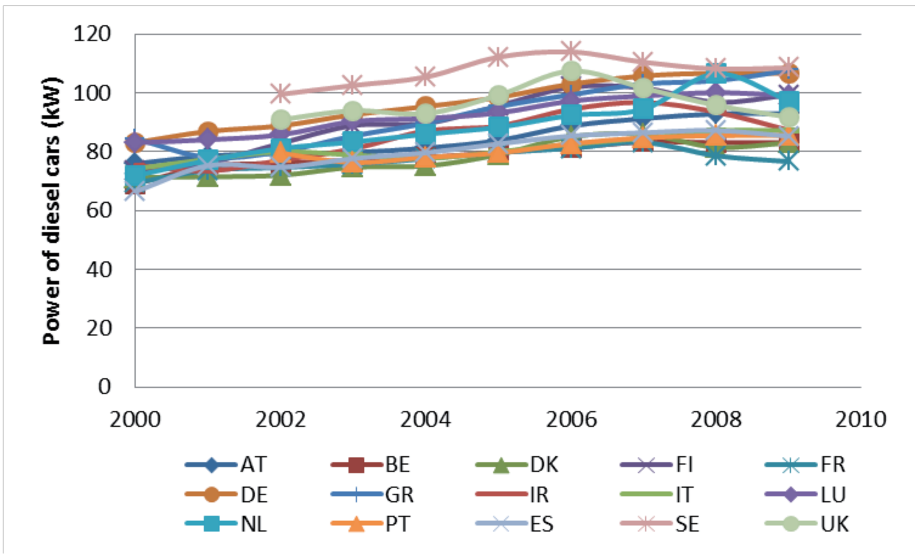

Figure 9. Development of power of diesel cars by country (2000–2009) (Data source: EC, 2009).

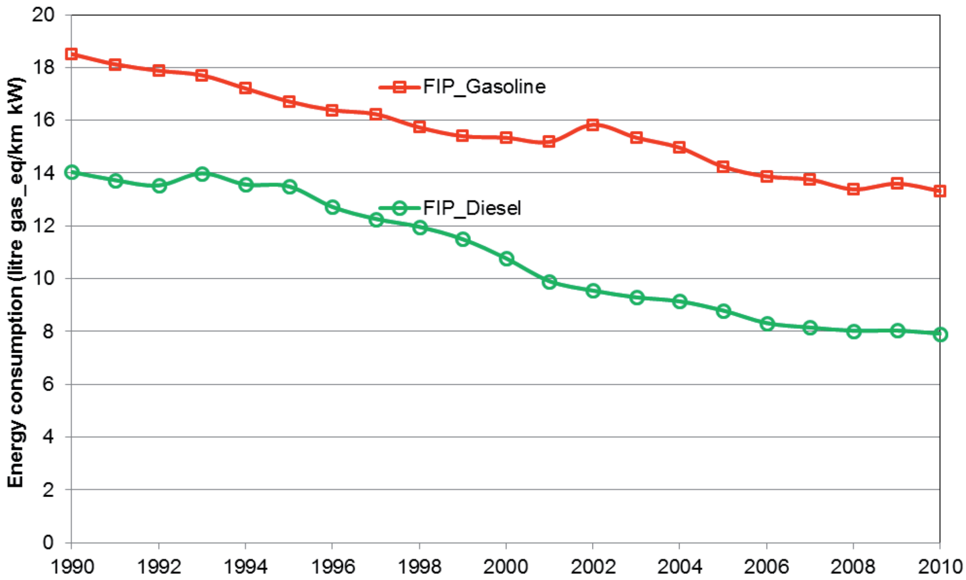

Figure 10. Energy consumption of cars in EU-15 per km driven and kW of power (2000–2010).

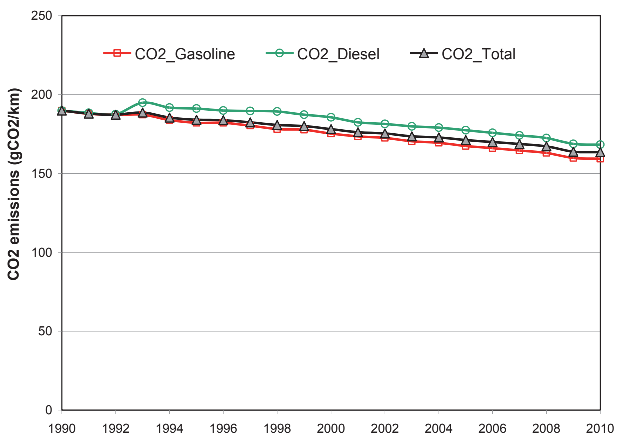

Figure 11a. CO_2 emissions of cars in EU-15 per km driven.

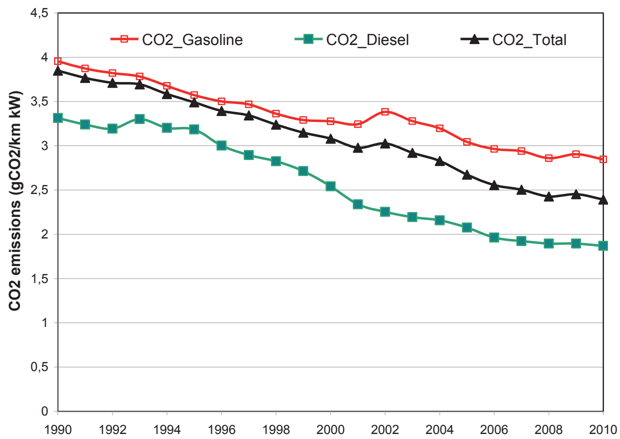

Figure 11b. CO_2 emissions of cars in EU-15 per km driven and kW of power.

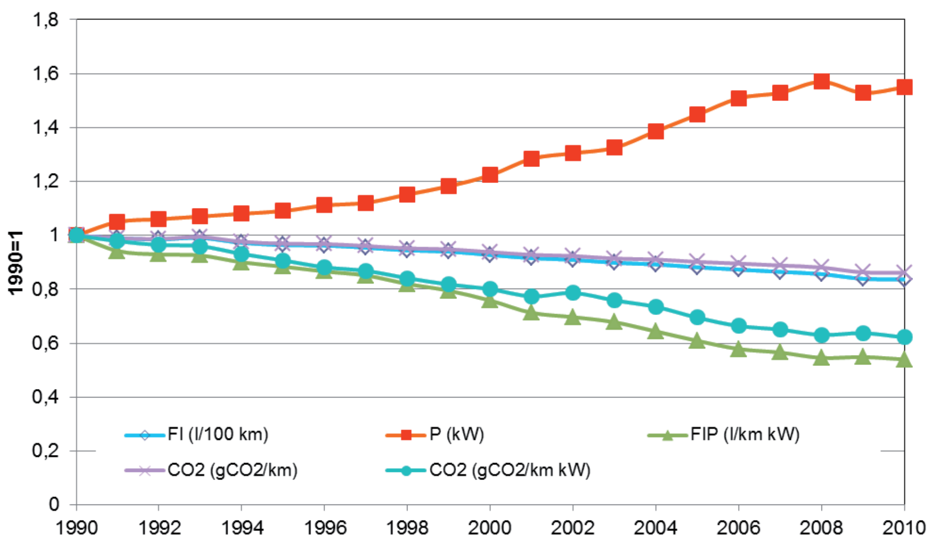

Figure 12. Index of fuel intensity, power, power-specific fuel intensity, CO_2 emissions and power specific CO_2 emissions (1990=1) for the average of EU-15 countries.

This FIP is depicted in Figure 10 for gasoline and diesel on average in EU-15 countries. The decrease in FIP from 1990 to 2010 was virtually twice as high as the decrease of FI in Figure 2. Moreover, also in contrary to Figure 2 the specific energy consumption of gasoline cars in EU-15 per km driven and kW of power is significantly higher than that of diesel cars.

Without the consideration of the car size CO_2 emissions of gasoline and diesel cars per km driven seems to be very similar, see Figure 11a. However, Figure 11b shows CO_2 emissions of cars in EU-15 per km driven and power and in this case significant difference between gasoline and diesel vehicles can be noticed.

Finally, Figure 12 shows normalised development (1990=1) of fuel intensity, power, power-specific fuel intensity, CO_2 emissions and power specific CO_2 emissions for the average of EU-15 countries. It can be clearly noticed that power of cars was continously increasing between 1990 and 2006. Afterwards stagnation took place. A slight decreas can be noticed in 2009. Over the whole investigated period CO_2 emissions and fuels intensity have been reduced. Yet, reduction of power-specific fuel intensity has been virtuelly about twice as high as the decrease of fuel intensity. Almost the same effect can be seen for power specific CO_2 emissions.

FI decreased by about 20 %. Regarding FIP there was a decrease of more than 40 % since 1990; that is to say, efficiency in 2010 was much higher than in 1990. However, about half of these theoretically possible energy savings has been compensated by the switch to larger cars and virtually the same effect can be seen for specific CO_2 emissions.

Conclusions

The major conclusions of this analysis are:

Looking at the whole WTW chain of providing the service mobility by passenger cars the largest energy saving effects took place in the TTW part. Virtually no efficiency gains are reported in the WTT part.

Policies that only address improvements of fuel intensity of cars fall short with respect to achieving the full potential of energy savings due to efficiency improvement. As this analysis has shown since 1990 about 50 % less energy has been conserved – and to the same magnitude less CO_2 emissions has been reduced – due to increases in cars, especially diesel cars.

This leads to the final conclusion that future energy policy has – in addition to FI improvement – to address the size issue e.g. by means of size-dependent registration taxes to avoid excessive increases in car size.

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